



GuideMyGrades

— YOUR GOALS. OUR EXPERTISE. —

OCR A LEVEL PHYSICS A (H556): QUESTIONS BY TOPIC

Gravitational fields (5.4)

A Level Physics A (H556) · Module 5: Newtonian world and astrophysics

38 questions · 236 marks · Mark schemes included

OCR A Level Physics A (H556), June 2017 – June 2025

 [guidemygrades.com](https://www.guidemygrades.com)

 [@Guidemygrades](https://www.instagram.com/Guidemygrades)

 [@Guidemygrades](https://www.twitter.com/Guidemygrades)

 [@Guidemygrades](https://www.youtube.com/Guidemygrades)

 info@guidemygrades.com

 Piccadilly Business Centre, Unit C, Aldow Enterprise Park
Blackett Street, Manchester, M12 6AE

HOW TO USE THIS BOOKLET

Questions run from the lowest mark tariff to the highest, so similar questions sit together.

Click any row below to jump straight to that question.

On every question page, click ANSWER in the top-right corner to jump to its mark scheme.

Diagrams, graphs, tables and data are printed exactly as they appeared in the original papers.

QUESTION	SOURCE	MARKS	PAGE
1. Q1	H556/01 Modelling physics June 2017	1	5
2. Q9 <i>also 3.3</i>	H556/01 Modelling physics June 2017	1	6
3. Q2 <i>also 3.3 & 3.1</i>	H556/01 Modelling physics June 2018	1	7
4. Q13 <i>also 3.3</i>	H556/01 Modelling physics June 2018	1	8
5. Q6	H556/01 Modelling physics June 2019	1	9
6. Q11	H556/01 Modelling physics June 2019	1	10
7. Q5	H556/01 Modelling physics November 2020	1	11
8. Q7 <i>also 3.5 & 3.3 & 5.2</i>	H556/01 Modelling physics November 2021	1	12
9. Q11	H556/01 Modelling physics November 2021	1	13
10. Q11 <i>also 3.5 & 3.3 & 3.1 & 5.2</i>	H556/01 Modelling physics June 2022	1	14
11. Q15 <i>also 6.2</i>	H556/02 Exploring physics June 2022	1	15
12. Q1 <i>also 2.3 & 3.5 & 3.3 & 3.1</i>	H556/01 Modelling physics June 2023	1	18
13. Q7	H556/01 Modelling physics June 2023	1	19
14. Q11	H556/01 Modelling physics June 2023	1	20
15. Q14	H556/01 Modelling physics June 2024	1	21
16. Q8 <i>also 5.2</i>	H556/01 Modelling physics June 2025	1	22
17. Q9	H556/01 Modelling physics June 2025	1	23
18. Q21 <i>also 5.5</i>	H556/01 Modelling physics June 2025	6	25
19. Q23	H556/01 Modelling physics June 2017	7	28
20. Q1 <i>also 3.1</i>	H556/03 Unified physics June 2023	7	30
21. Q24 <i>also 3.2 & 5.5</i>	H556/01 Modelling physics June 2019	8	33
22. Q20 <i>also 3.3</i>	H556/01 Modelling physics November 2021	8	36
23. Q22 <i>also 3.5 & 3.3</i>	H556/01 Modelling physics June 2025	8	38
24. Q23 <i>also 5.5 & 5.1</i>	H556/01 Modelling physics June 2019	9	41
25. Q23 <i>also 3.3 & 5.2</i>	H556/01 Modelling physics June 2022	9	44
26. Q22 <i>also 3.5 & 5.1</i>	H556/01 Modelling physics June 2018	10	47
27. Q3 <i>also 3.2</i>	H556/03 Unified physics June 2018	10	49
28. Q23	H556/01 Modelling physics November 2020	10	51
29. Q23 <i>also 2.2 & 3.3 & 5.5 & 5.1</i>	H556/01 Modelling physics June 2023	10	54
30. Q20 <i>also 3.5 & 3.3</i>	H556/01 Modelling physics June 2018	11	57



	QUESTION		SOURCE	MARKS	PAGE
31.	Q21	<i>also 3.4 & 3.3 & 3.1 & 5.3</i>	H556/01 Modelling physics November 2021	11	60
32.	Q1	<i>also 2.1 & 3.2 & 3.1 & 5.2</i>	H556/03 Unified physics June 2022	12	63
33.	Q3	<i>also 3.3 & 6.3</i>	H556/03 Unified physics June 2025	12	66
34.	Q4	<i>also 3.1 & 5.1</i>	H556/03 Unified physics November 2020	13	69
35.	Q3	<i>also 3.3 & 6.4</i>	H556/03 Unified physics November 2021	13	72
36.	Q22	<i>also 3.3 & 5.2</i>	H556/01 Modelling physics June 2024	14	75
37.	Q23	<i>also 2.1 & 2.2 & 4.4 & 5.5</i>	H556/01 Modelling physics November 2021	15	79
38.	Q17	<i>also 2.2</i>	H556/01 Modelling physics June 2018	16	82



QUESTIONS

38 questions · 236 marks · lowest tariff first



MULTIPLE-CHOICE QUESTIONS

17 questions in this booklet



1 Which of the following is a correct unit for gravitational field strength?

A J kg^{-1}

B N kg^{-1}

C $\text{Nm}^2\text{kg}^{-2}$

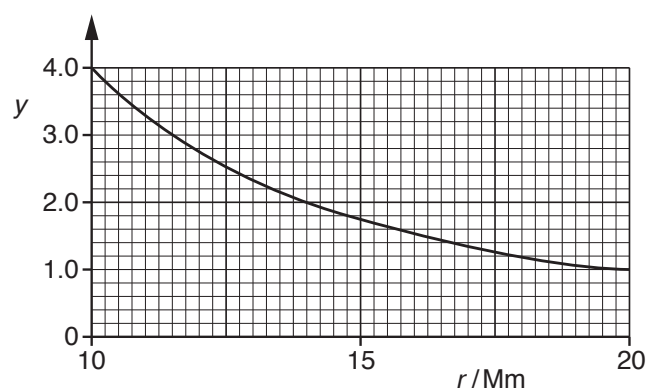
D kg ms^{-1}

Your answer

[1]



- 9 A graph of y against distance r from the centre of a planet is shown below.



The graph shows that y is inversely proportional to r^2 .

Which quantity is best represented on the y -axis of the graph?

- A Period of a satellite orbiting the planet.
- B Gravitational potential of the planet.
- C Gravitational field strength of the planet.
- D Kinetic energy of a satellite orbiting the planet.

Your answer

[1]

- 2 Which set of quantities are all scalar?
- A acceleration, displacement, velocity
 - B energy, mass, power
 - C extension, force, gravitational potential energy
 - D weight, kinetic energy, work done

Your answer

[1]



- 13** Earth has a mass of 6.0×10^{24} kg and a radius of 6400 km.
A satellite of mass 320 kg is lifted from the Earth's surface to an orbit 1200 km above its surface.

What is the change in the gravitational potential energy of the satellite?

A 9.1×10^2 J

B 9.9×10^6 J

C 3.2×10^9 J

D 3.8×10^9 J

Your answer

[1]



- 6 The Earth is surrounded by a gravitational field.

Which of the following statements is/are correct about the gravitational field lines near the **surface** of the Earth.

- 1 They are parallel.
- 2 They show the direction of the force on a small mass.
- 3 They are equally spaced.

A Only 1

B Only 1 and 2

C Only 2 and 3

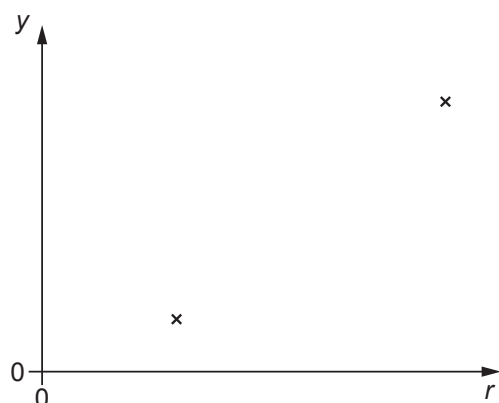
D 1, 2 and 3

Your answer

[1]



- 11 A student has collected some data on the Solar System.
The student plots a graph, but only two data points are shown below.



The distance from the centre of the Sun is r .

Which quantity y is represented on the vertical axis?

- A Speed of a planet.
- B Period of a planet.
- C Gravitational potential of the Sun.
- D Gravitational field strength of the Sun.

Your answer

[1]

5 The gravitational force between two point-mass objects **X** and **Y** is F_1 .

The mass of **X** increases and the distance between **X** and **Y** is halved.

Which statement about the new gravitational force F_2 between these two objects is correct?

A $0 < F_2 < 0.25F_1$

B $F_2 > 4F_1$

C $F_2 = F_1$

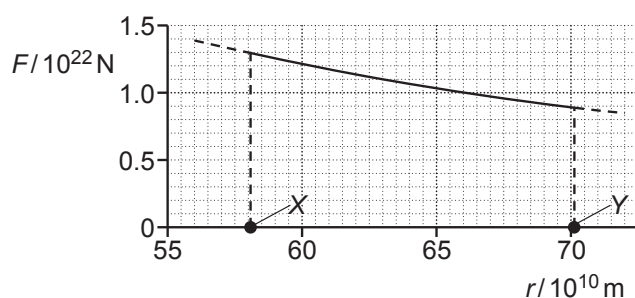
D $2F_1 < F_2 < 4F_1$

Your answer

[1]

- 7 The planet Mercury has a highly elliptical orbit around the Sun.

The gravitational force F acting on Mercury due to the Sun varies with its distance r from the centre of the Sun. The graph of F against r for Mercury in its orbit is shown below.



Mercury is closest to the Sun when $r = X$ and furthest when $r = Y$.

What does the **area** under the graph between the distances X and Y represent?

- A The centripetal force acting on Mercury.
- B The change in the gravitational potential energy of Mercury.
- C The impulse of the force acting on Mercury.
- D The kinetic energy of Mercury.

Your answer

[1]

- 11 Kepler-90 is a star with several planets orbiting it.
The two outermost planets are Kepler-90g and Kepler-90h.
Kepler-90g has an orbital period of 210 days and is 0.71AU from the centre of Kepler-90.
Kepler-90h is 1.01AU from the centre of Kepler-90.

Kepler's third law of planetary motion can be applied to the planets of Kepler-90.

What is the orbital period of Kepler-90h?

- A 50 days
- B 299 days
- C 356 days
- D 4350 days

Your answer

[1]



11 Which pair of quantities do **not** have the same, or equivalent, units?

- A acceleration, gravitational field strength
- B angular frequency, angular velocity
- C gravitational potential, kinetic energy
- D impulse, momentum

Your answer

[1]

© OCR 2022

Turn over



- 15** An electron has both mass and charge. The electron has a gravitational field and an electric field around it.

Which statement is **not** correct?

- A** Both field patterns look the same.
- B** Both field patterns show parallel field lines around the electron.
- C** Both field strengths obey an inverse square law with distance from the electron.
- D** The direction of both fields is the same at any point around the electron.

Your answer

[1]

BLANK PAGE

PLEASE DO NOT WRITE ON THIS PAGE



SECTION B

Answer **all** the questions.



1 Which row contains **only** scalar quantities?

A Absolute temperature, displacement, moment

B Acceleration, force, momentum

C Gravitational potential, kinetic energy, mass

D Kinetic energy, mass, momentum

Your answer

[1]

- 7 Two identical spheres, each of mass 8700 kg, have a space of 3.6 m between their centres.

What is the magnitude of the gravitational force they exert on each other?

A $2.0 \times 10^{-3} \text{ N}$

B $3.9 \times 10^{-4} \text{ N}$

C $7.5 \times 10^{-4} \text{ N}$

D $4.5 \times 10^{-8} \text{ N}$

Your answer

[1]



- 11 A satellite is in geostationary orbit 36 000 km above the Earth's surface. The Earth has a radius of 6400 km.

At what speed is the satellite moving relative to the centre of the Earth?

- A 0 m s^{-1}
- B 490 m s^{-1}
- C 2.6 km s^{-1}
- D 3.1 km s^{-1}

Your answer

[1]

14 At the surface of a planet with radius r the magnitude of the gravitational field strength is g .

What is the escape velocity from the surface of the planet?

A $\sqrt{rg}$

B $\sqrt{2g}$

C $\sqrt{2rg}$

D $2rg$

Your answer

[1]



- 8 A washing machine with a circular drum of diameter 0.60 m is rotating at an angular velocity of 15 radians per second.

What is the magnitude of the force exerted by the drum on a 0.30 kg item of clothing which is at the bottom of the spinning drum?

- A 21 N
B 23 N
C 41 N
D 43 N

Your answer

[1]

© 2025 Cambridge Assessment International Education. All rights reserved. Cambridge International AS & A Level Physics, 9709/23/24

- 9 Two spheres each of radius 10 m and mass 1600 kg exert a gravitational force of 1.7×10^{-8} N on each other.

What is the shortest distance between the surfaces of the spheres?

- A 80 m
- B 100 m
- C 120 m
- D 9900 m

Your answer

[1]

© OCR 2025



6-MARK QUESTIONS

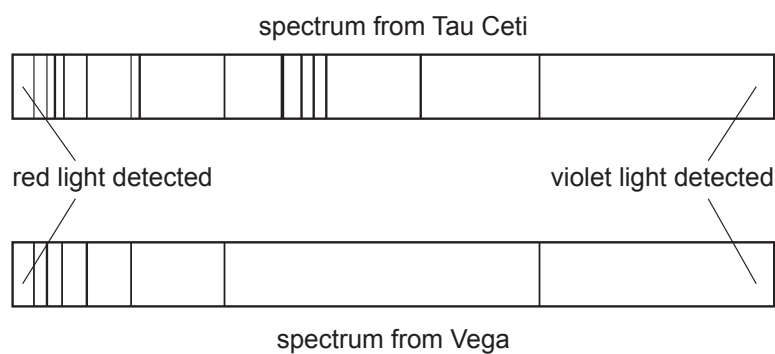
1 question in this booklet



21* Analysis of stellar light can identify the elements that are present in the outer layers of a star.

Absorption spectra of visible light collected from two main sequence stars, Vega and Tau Ceti, are shown below. The spectra were collected by a telescope orbiting the Earth. The dark lines on the diagram show wavelengths where the intensity was zero or close to zero.

- Explain the cause of the dark lines.
- Describe and explain at least one difference between the spectra.
- Analyse the spectra to determine which star is older.



[6]

Additional space if required

.....

.....

.....

.....

.....



7-MARK QUESTIONS

2 questions in this booklet



- 23 (a) Write an expression for the gravitational potential V_g at the surface of a planet of mass M and radius r .

[1]

- (b) The table below shows some data for Mercury and Pluto.

	Mass/kg	Radius/m	Mean distance from Sun/m
Mercury	3.30×10^{23}	2.44×10^6	57.9×10^9
Pluto	0.131×10^{23}	1.19×10^6	5910×10^9

- (i) Show that the escape velocity v of a gas molecule on the surface of Pluto is given by the equation

$$v = \sqrt{\frac{2GM}{r}}$$

where M is the mass of Pluto and r is its radius.

[2]

- (ii) Calculate the escape velocity v of gas molecules on the surface of Pluto.

$$v = \dots\dots\dots \text{ms}^{-1} \quad [1]$$

- (iii) Explain why Mercury has no atmosphere whilst Pluto still has a thin atmosphere. Use data from the table to support your explanation.

.....

.....

.....

.....

.....

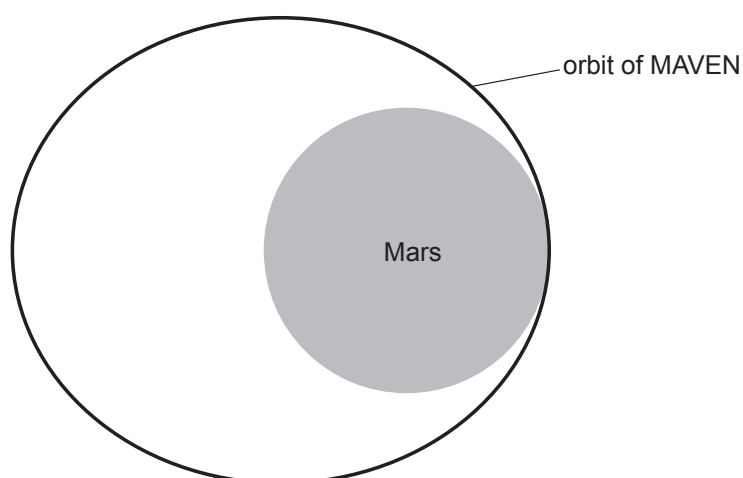
.....

..... [3]



1 The MAVEN spacecraft orbits Mars and studies its upper atmosphere.

(a) The diagram below shows the orbit of MAVEN around Mars.



(i) Mark an **X** on the diagram to show the point in the orbit where MAVEN has maximum acceleration. [1]

(ii) Explain how Kepler's 1st law applies to MAVEN's orbit around Mars.

.....

.....

.....

..... [2]

(b) The table shows data for four orbits around Mars.

Phobos and Deimos are moons of Mars.

An areostationary orbit for Mars is the equivalent of a geostationary orbit for Earth.

Orbit	Time period/hours	Average distance from centre of Mars/km
MAVEN	4.5	6 500
Phobos	7.7	9 400
Deimos	30	23 000
Areostationary	25	20 000

(i) Show that Kepler’s 3rd law applies to this data.

[2]

(ii) Suggest **two** reasons why MAVEN was **not** placed in an areostationary orbit.

1

.....

.....

2

.....

.....

[2]

8-MARK QUESTIONS

3 questions in this booklet



- 24 (a)** Proxima Centauri is the closest star to Earth.
Fig. 24.1 shows the apparent positions of this star against the background of very distant stars as seen from the Earth over a period of exactly 6 months.

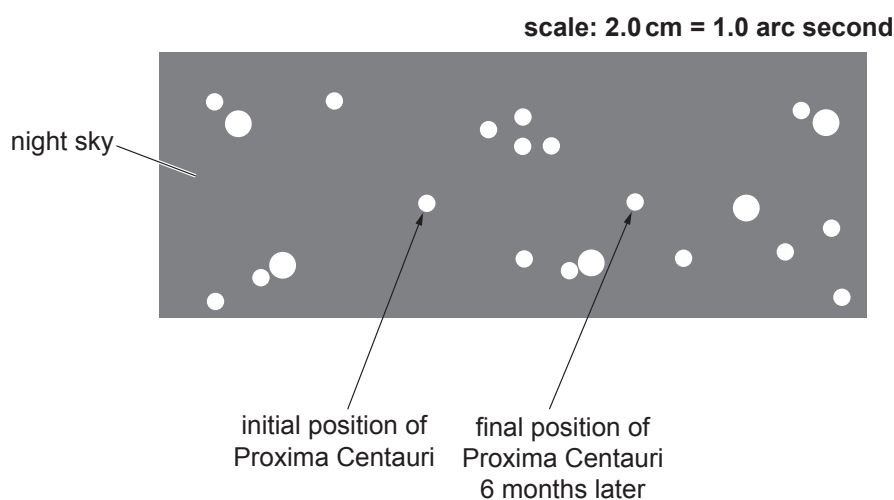


Fig. 24.1

The parallax angle for Proxima Centauri can be determined from Fig. 24.1 using the scale provided.

- (i)** Show that the parallax angle p for Proxima Centauri is about 0.8 arc second.

[2]

Question 24 continues on page 30

- (ii) Use your answer in (i) to calculate the distance d of Proxima Centauri from the Earth in light-years (ly).

$$1 \text{ pc} = 3.26 \text{ ly}$$

$$d = \dots\dots\dots \text{ ly} \text{ [2]}$$

- (b) The galaxies in the Universe may be assumed to be distributed uniformly through space.

In this model, the separation between two neighbouring galaxies is $1.4 \times 10^{23} \text{ m}$ and each galaxy occupies a cube of space of volume $2.7 \times 10^{69} \text{ m}^3$ as shown in Fig. 24.2.

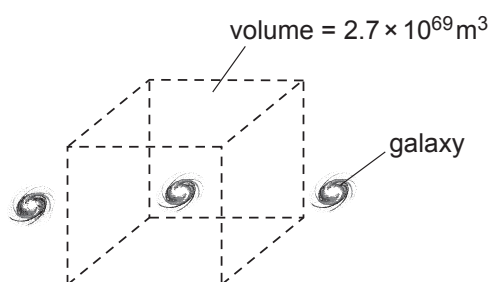


Fig. 24.2

There are on average 10^{11} stars in each galaxy and the mass of an average star is about $2.0 \times 10^{30} \text{ kg}$.

- (i) Estimate the gravitational force between two neighbouring galaxies.

force = ... N [2]

- (ii) Show that the mean density of the Universe is about $7 \times 10^{-29} \text{ kg m}^{-3}$.

[1]

- (iii) Suggest why the actual mean density of the Universe is different from the value calculated in (ii).

.....

..... [1]



20 (a) The diagram below shows the Earth in space.



- (i) On the diagram above, draw a minimum of **four** gravitational field lines to map out the gravitational field pattern around the Earth. [1]
- (ii) On the same diagram above, show **two** different points where the gravitational potential is the same. Label these points **X** and **Y**. [1]
- (b)* A satellite is in a circular geostationary orbit around the centre of the Earth. The satellite has both kinetic energy and gravitational potential energy.

The mass of the satellite is 2500 kg and the radius of its circular orbit is 4.22×10^7 m.
The mass of the Earth is 5.97×10^{24} kg.

- Describe some of the features of a geostationary orbit.
- Calculate the **total** energy of the satellite in its geostationary orbit. [6]

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

Additional answer space if required.

.....

.....

.....

.....

.....

.....

.....

.....

- 22** An asteroid of mass 10 kg is in a circular orbit around the Sun at a distance of 3.5AU from the centre of the Sun.

$$1\text{ AU} = 1.5 \times 10^{11}\text{ m}$$

(a)

- (i)** Use Kepler's third law to calculate the period of the orbit of the asteroid in years.

An object orbiting the Sun at a distance of 1AU has a period of 1 year.

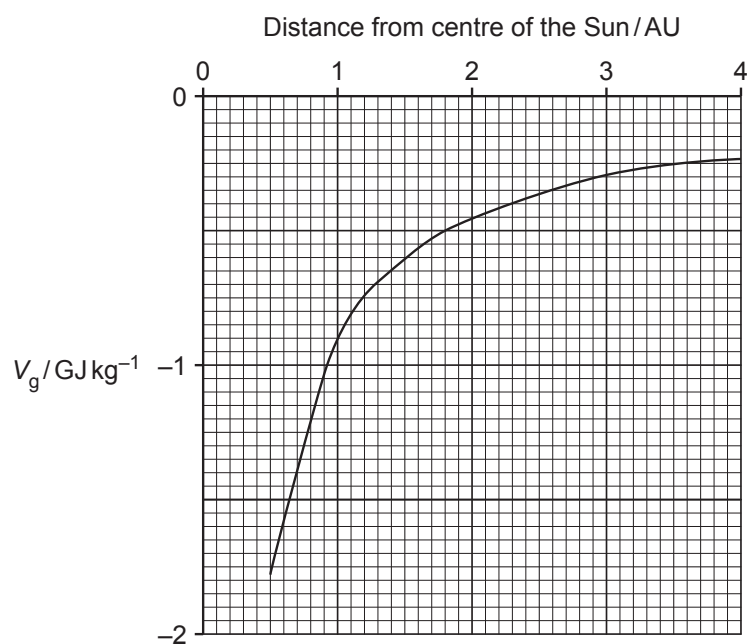
period = ... years **[2]**

- (ii)** Calculate the kinetic energy of the asteroid.

kinetic energy = ... J **[3]**

- (b) After a collision the asteroid falls towards the Sun.

The graph below shows the variation of gravitational potential, V_g , due to the Sun with the distance from the centre of the Sun.



- (i) Use the graph to calculate the change in gravitational potential energy of the satellite from the moment of collision until it crosses the Earth's orbit.

change in gravitational potential energy = ... GJ [2]

- (ii) Eventually, the asteroid falls into a new orbit around the Sun. This orbit is elliptical.

State the other feature of this orbit predicted by Kepler's first law.

.....
 [1]

9-MARK QUESTIONS

2 questions in this booklet



- 23 (a)* In 2017, an ultra-cool star TRAPPIST-1 was discovered with at least five of its own orbiting planets. Astronomers are interested about the possibility of finding life on some of the planets orbiting TRAPPIST-1.

The table below shows some data.

	TRAPPIST-1	Sun
Luminosity L/W	2.0×10^{23}	3.8×10^{26}
Surface temperature T/K	2500	5800
Radius of star/m	R	7.0×10^8
Distance between Earth and Sun/m		1.5×10^{11}
Distance between planets and TRAPPIST-1/m	1.6×10^9 to 9.0×10^9	

The temperature T in kelvin of a planet, its distance d from the star and the luminosity L of the star are related by the expression

$$\frac{T^4 d^2}{L} = \text{constant.}$$

- The average temperature of the Earth is about 290 K. Explain how life may be possible on some of the planets orbiting TRAPPIST-1.
- Use your knowledge of luminosity to show that the radius R of TRAPPIST-1 is smaller than the Sun.
- Support your answers by calculations. [6]

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

Additional answer space if required.

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

Question 23 continues on page 28

(b) Kepler's third law can be applied to a satellite in a geostationary orbit around the Earth.

- (i) Complete the equation for Kepler's third law below.
You do not need to define any of the terms.

$$\text{.....} = \frac{4\pi^2}{GM} \text{.....} \quad [1]$$

- (ii) The mass of Earth is 6.0×10^{24} kg.
Calculate the radius of the circular path of a satellite in a geostationary orbit around the Earth.

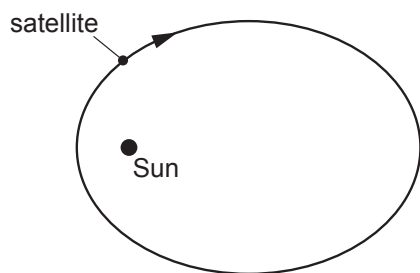
radius = ... m [2]

- 23 (a)** A planet of mass m is in a circular orbit around a star of mass M .

Use the equation for Newton's law of gravitation and your knowledge of circular motion to show that the relationship between the orbital period T of the planet and its orbital radius r is $T^2 \propto r^3$.

[3]

- (b)** The Solar Orbiter satellite was launched in February 2020.
This satellite moves around the Sun in an elliptical orbit with a period of 168 days.
The diagram below shows the elliptical orbit of this satellite.



The closest distance of the satellite to the Sun is 4.20×10^{10} m and its furthest distance from the Sun is 1.37×10^{11} m.

The mass of the Sun is 2.0×10^{30} kg and the mass of the satellite is 209 kg.

- (i) The Earth has a mean orbital distance of 1.50×10^{11} m around the Sun and an orbital period of 365 days.

Use **Kepler's third law** to calculate the mean orbital distance of the satellite from the Sun.

distance = ... m [2]

- (ii) The total kinetic and gravitational potential energy of the satellite in its orbit remains constant.

Calculate the change in the kinetic energy of the satellite as it travels from its furthest point from the Sun to its closest point to the Sun.

change in kinetic energy = ... J [3]

- (iii) Suggest why the total energy of the satellite in its orbit around the Sun is not the same as the total energy of the satellite during its launch from the surface of the Earth.

.....

..... [1]



10-MARK QUESTIONS

4 questions in this booklet



- 22 (a) A helium atom **X** travelling at 610 m s^{-1} makes an elastic collision with a stationary helium atom **Y**. The magnitude of the velocity of **X** after the collision is 258 m s^{-1} . The directions of the velocities of **X** and **Y** are as shown in Fig. 22.

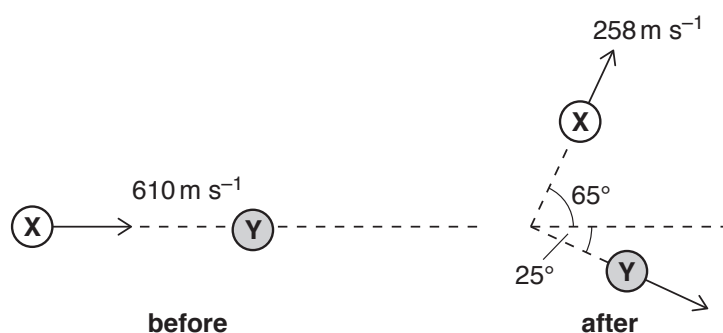


Fig. 22

- (i) Explain what is meant by an *elastic collision*.

.....
 [1]

- (ii) The mass of a helium atom is $6.64 \times 10^{-27} \text{ kg}$.
 Calculate the magnitude of the momentum p of **Y** after the collision.

$p = \dots\dots\dots \text{ kg m s}^{-1}$ [3]

- (b)* There is a lot of helium in the Universe. This was also true of the Earth when it was formed billions of years ago. However, only small traces of helium are now found in the atmosphere of the Earth.

Use the kinetic theory of gases to explain why only small amounts of helium are found in the Earth's atmosphere. Use the information below to do suitable calculations to support your answer.

- typical atmospheric temperature = 10°C
- mass of helium atom = $6.64 \times 10^{-27} \text{ kg}$
- escape velocity from the Earth = 11 km s^{-1}

Turn over



- 3 A binary star is a pair of stars which move in circular orbits around their common centre of mass. In this question consider the stars to be point masses situated at their centres.

(a) Fig. 3.1 shows a binary star where the mass of each star is m . The stars move in the same circular orbit.

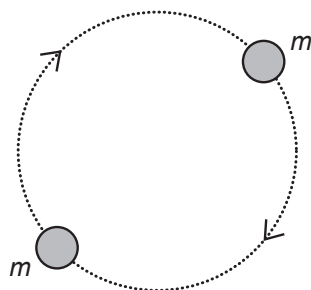


Fig. 3.1

- (i) Explain why the stars of equal mass must always be diametrically opposite as they travel in the circular orbit.

.....

.....

.....

.....

..... [2]

- (ii) The centres of the two stars are separated by a distance of $2R$ equal to $3.6 \times 10^{10} \text{ m}$, where R is the radius of the orbit. The stars have an orbital period T of 20.5 days. The mass of each star is given by the equation

$$m = \frac{16\pi^2 R^3}{GT^2}$$

where G is the gravitational constant.

Calculate the mass m of each star in terms of the mass $M_{\odot}$ of the Sun.

$$1 \text{ day} = 86400 \text{ s}$$

$$M_{\odot} = 2.0 \times 10^{30} \text{ kg}$$

$$m = \dots\dots\dots M_{\odot} \text{ [3]}$$

- (iii) The stars are viewed from Earth in the plane of rotation.
The stars are observed using light that has wavelength of 656 nm in the laboratory. The observed light from the stars is Doppler shifted.

Calculate the maximum change in the observed wavelength $\Delta\lambda$ of this light from the orbiting stars. Give your answer in nm.

$\Delta\lambda = \dots\dots\dots$ nm [2]

- (b) Fig. 3.2 shows a binary star where the masses of the stars are $4m$ and m .

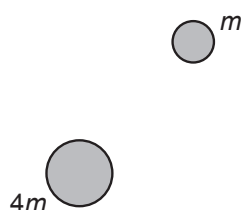


Fig. 3.2

- (i) The centre of mass of the binary star lies at the surface of the star of mass $4m$. Draw on Fig. 3.2 two circles to represent the orbits of **both** stars. [1]

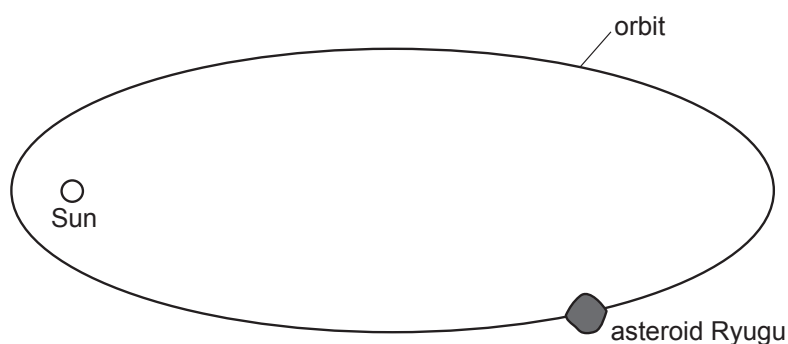
- (ii) Explain why the smaller mass star travels faster in its orbit than the larger mass star.

.....

 [2]

23 In June 2018, the spacecraft Hayabusa2 arrived at an asteroid called Ryugu.

(a) The asteroid orbits the Sun in an elliptical orbit as shown below.



The diagram is **not** drawn to scale.

(i) Indicate with a letter **X** on the orbit where the asteroid would be moving at maximum speed. **[1]**

(ii) Use Kepler's **second law** to explain your answer to **(a)(i)**.

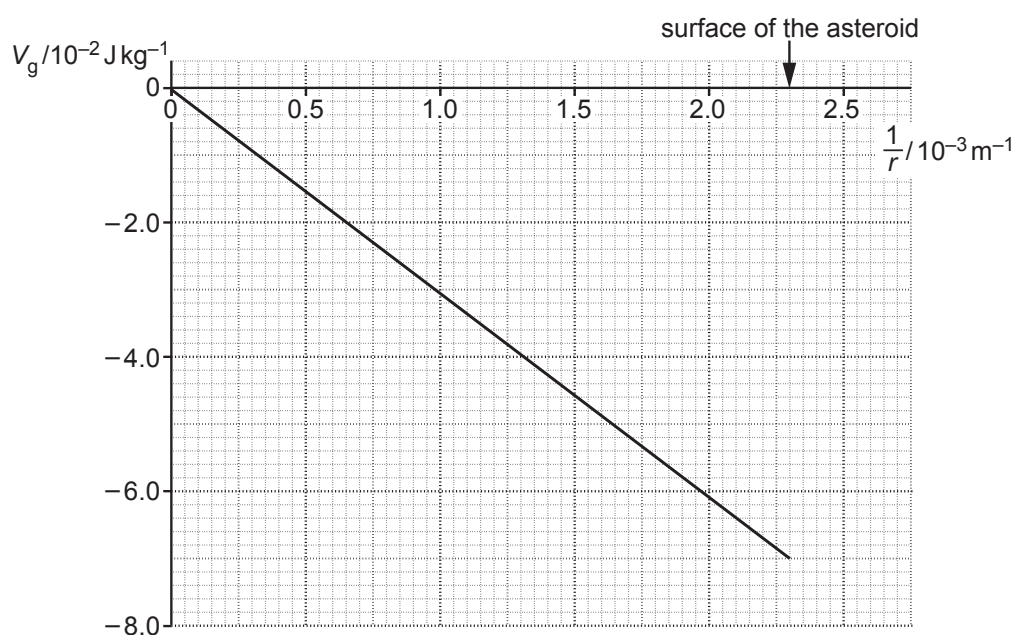
.....

.....

.....

..... **[2]**

- (b) The gravitational potential at a distance r from the centre of the asteroid Ryugu is V_g . The graph of V_g against $\frac{1}{r}$ for the asteroid is shown below.



- (i) Define **gravitational potential**.

.....

 [1]

- (ii) Show that the magnitude of the gradient of the graph is equal to GM , where M is the mass of the asteroid and G is the gravitational constant.

[1]

- (iii) Use the gradient of the graph to show that the mass M of the asteroid is about $4.6 \times 10^{11} \text{ kg}$.

$M = \dots\dots\dots \text{ kg}$ [2]

- (c) In October 2018, the probe Mobile Asteroid Surface Scout (MASCOT) was released from **rest** from the Hayabusa2 spacecraft from a distance of 600 m from the centre of the asteroid.

Assume that the spacecraft was stationary relative to the asteroid when MASCOT was dropped.

Use information from (b) to calculate the speed of the impact v when MASCOT landed on the surface of the asteroid.

$v = \dots\dots\dots \text{ ms}^{-1}$ [3]

Question 24 is on page 30

- 23** The Hipparcos space telescope used stellar parallax with a precision of 9.7×10^{-4} arcseconds to determine the distance to stars.

One of the stars studied was Polaris A. Data about this star is in the table below.

Parallax angle	7.5×10^{-3} arcseconds
Radius	2.1×10^{10} m
Mass	1.1×10^{31} kg
Surface temperature	6000 K
Temperature of the atmosphere of the star	4.0×10^6 K

- (a) (i)** Estimate the maximum stellar distance in parsecs that could be measured using Hipparcos.

maximum stellar distance = ...pc **[1]**

- (ii)** Calculate the percentage uncertainty in the calculated value of the distance to Polaris A.

percentage uncertainty = ... % **[2]**

- (b)** A continuous stream of particles called a solar wind flows from the surface of the star into the surrounding space.

These particles include helium nuclei of mass 6.6×10^{-27} kg.

Assume that the atmosphere is modelled as an ideal gas.

- (i)** Show that the typical kinetic energy of a helium nucleus in the atmosphere is about 10^{-16} J.

[2]

- (ii) The gravitational potential energy of a helium nucleus in the outer layer of the star is $-2.3 \times 10^{-16} \text{ J}$.

Calculate the gravitational potential energy U at the maximum distance from the star that a helium nucleus could reach.

$U = \dots\dots\dots \text{ J [1]}$

- (iii) Calculate the distance from the centre of the star reached by this helium nucleus.

distance = $\dots\dots\dots \text{ m [3]}$

- (iv) Explain why the star has a solar wind that reaches a much greater distance from the star than found in (iii).

$\dots\dots\dots$
 $\dots\dots\dots \text{ [1]}$



11-MARK QUESTIONS

2 questions in this booklet



- 20 (a) Use the equations for momentum and kinetic energy to derive an expression for the kinetic energy E_k of a particle in terms of its momentum p and mass m .

[2]

- (b) Fig. 20.1 shows an electric motor used to lift and lower a load.

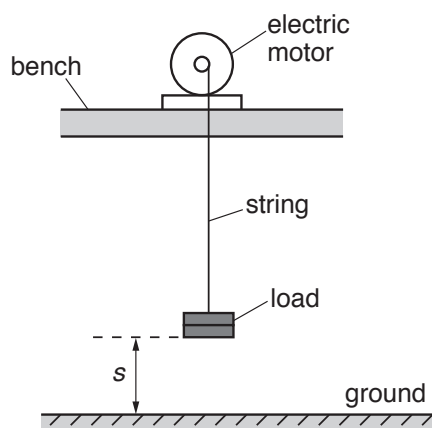


Fig. 20.1

At time $t = 0$ the load is on the ground with displacement $s = 0$.

Fig. 20.2 shows the variation of the displacement s of the load with time t .

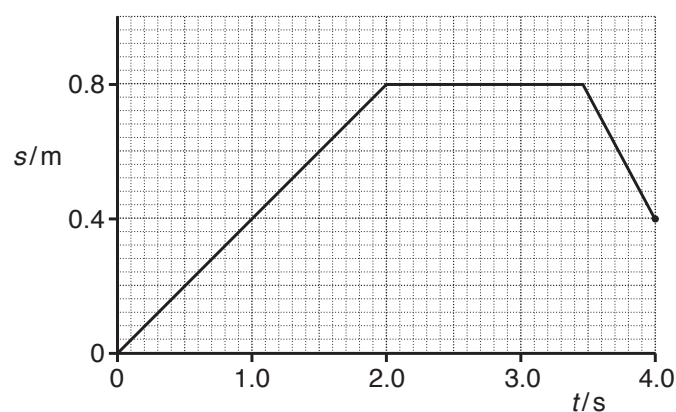


Fig. 20.2

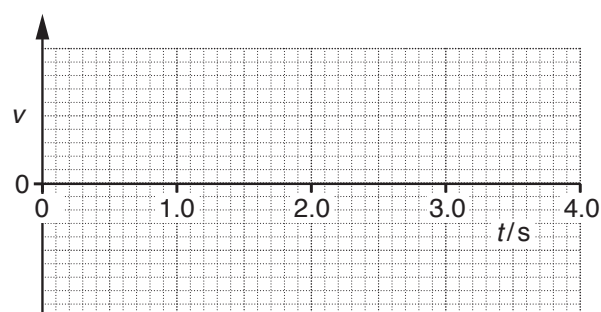


Fig. 20.3

- (i) On Fig. 20.3, sketch a graph to show the variation of the velocity v of the load with time t . You do not need to insert a scale on the v axis. **[3]**
- (ii) Describe how the kinetic energy and the gravitational potential energy of the load varies from $t = 0$ to $t = 2.0$ s.

.....

.....

.....

..... **[2]**

- (iii) During the **downward** journey of the load, the string breaks at $t = 4.0$ s. It then falls vertically towards the ground. The mass of the load is 120 g. Air resistance is negligible.

1 Calculate the velocity V of the load just before it hits the ground.

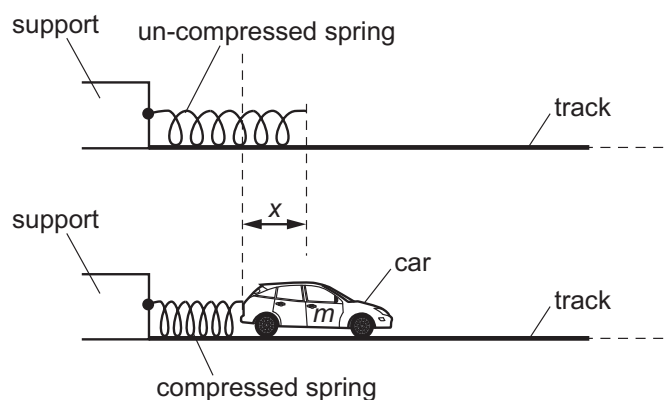
$$V = \dots\dots\dots \text{ms}^{-1} \text{ [2]}$$

2 The load hits the ground and comes to **rest** in a time interval of 25 ms.

Calculate the average force F exerted by the ground on the load.

$$F = \dots\dots\dots \text{N [2]}$$

- 21 (a) One end of a spring is fixed to a support. A toy car, which is on a smooth horizontal track, is pushed against the free end of the spring. The spring compresses. The car is then released. The car accelerates to the right until the spring returns back to its original length.



The car moves with **simple harmonic motion** as the spring returns to its original length.

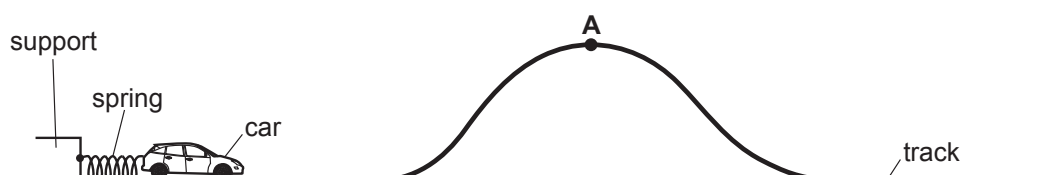
The acceleration of the car is given by the expression $a = -\left(\frac{k}{m}\right)x$, where m is the mass of the car, k is the force constant of the spring and x is the compression of the spring.

Use the data below to calculate the time t it takes for the spring to return to its original length after the car is released.

- mass of car $m = 80 \text{ g}$
- force constant k of the spring $= 60 \text{ N m}^{-1}$.

$t = \dots\dots\dots \text{ s}$ [4]

- (b) The arrangement in (a) is used to propel the toy car along a smooth track.



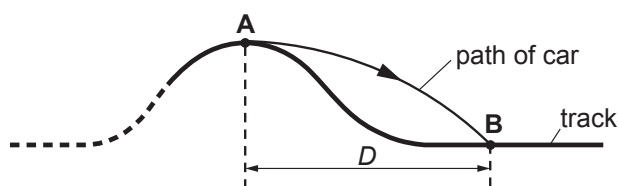
- (i) Point **A** is at the top of the track.
The launch speed of the car is now adjusted until the car just reaches **A** with zero speed.
The height of **A** is 0.20 m above the horizontal section of the track.

All the elastic potential energy of the spring is transferred to gravitational potential energy of the car.

Calculate the initial compression x of the spring.

$x = \dots\dots\dots$ m [3]

- (ii) At a specific speed, the car leaves point **A** horizontally and lands on the track at point **B**.
The horizontal distance between **A** and **B** is D .



Air resistance has negligible effect on the motion of the car between **A** and **B**.

- 1 Explain how the time of flight between **A** and **B** depends on the speed of the car at **A**.

.....

 [2]

- 2 Explain how the distance D depends on the speed of the car at **A**.

.....

 [2]

12-MARK QUESTIONS

2 questions in this booklet



- 1 The table shows some data on the planet Venus.

Mass/kg	4.87×10^{24}
Radius/km	6050
Density of atmosphere at surface/ kg m^{-3}	65
Period of rotation about its axis/hours	5830

- (a) Calculate the magnitude of the gravitational field strength g at the surface of Venus.

Give your answer to **3** significant figures.

$$g = \dots\dots\dots \text{N kg}^{-1} \text{ [3]}$$

- (b) Two identical space probes, **A** and **B**, land on a flat surface on Venus.

Probe **A** lands at the north pole. Probe **B** lands on the equator.

Each probe has mass 760 kg and volume 1.7 m^3 .

- (i) Calculate the centripetal acceleration a of probe **B** at the equator due to the rotation of Venus about its axis.

$$a = \dots\dots\dots \text{ms}^{-2} \text{ [3]}$$

- (ii) The atmosphere exerts the same upthrust on each probe.

Using your answer to (a), calculate the upthrust acting on each probe.

upthrust = ... N [3]

- (iii) Explain which probe will experience the greater normal contact force from the surface of Venus.

.....
.....
.....
.....
.....
..... [3]

BLANK PAGE

PLEASE DO NOT WRITE ON THIS PAGE



3 This question is about comparing two methods for storing energy.

(a) A proposed method for storing energy uses trucks powered by electric motors.

The trucks carry sand up a mountain, storing surplus energy as gravitational potential energy.

When the energy needs to be released, they carry the sand back down the mountain, converting the gravitational potential energy into chemical energy stored in a battery.

Explain how an electrical generator in the truck could use **electromagnetic induction** to convert gravitational potential energy into chemical energy stored in a battery.

.....

.....

.....

.....

.....

..... [3]

(b) A second proposed method for storing energy uses a tank of wax.

The wax is heated using an electrical heater, storing surplus energy as internal energy of the wax. The wax increases in temperature and melts as it is heated.

When the energy needs to be released, the wax is allowed to cool, converting the internal energy of the wax into thermal energy.

Explain, in terms of the particles in the wax, how energy is stored when it is heated.

.....

.....

.....

.....

.....

..... [3]

(c)* A gravitational potential energy storage system, as described in (a), is proposed as follows:

- height of mountain = 1 km
- overall efficiency = 70 %

A thermal energy storage system, as described in (b), is proposed as follows:

- lower operating temperature = 18 °C
- melting point of wax = 51 °C
- upper operating temperature = 70 °C
- specific heat capacity of solid wax = $2.6 \text{ kJ kg}^{-1} \text{ K}^{-1}$

© OCR 2025

- specific heat capacity of liquid wax = $3.0 \text{ kJ kg}^{-1} \text{ K}^{-1}$
- specific latent heat of fusion of wax = 160 kJ kg^{-1}
- overall efficiency = 95 %

Estimate the energy that can be stored by each system using 1 kg of sand or wax.

Discuss which system would be more appropriate for storing surplus electrical energy. Your answer should include an estimate of the energy that can be stored in each system using 1 kg of sand or wax.

Ignore any financial factors.

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

Additional answer space if required

.....

.....

.....

.....

.....

.....

.....

..... [6]

13-MARK QUESTIONS

2 questions in this booklet



- 4 The International Space Station (ISS) orbits the Earth at a height of $4.1 \times 10^5 \text{ m}$ **above** the Earth's surface.

The radius of the Earth is $6.37 \times 10^6 \text{ m}$. The gravitational field strength g_0 at the Earth's surface is 9.81 N kg^{-1} .

- (a) Both the ISS and the astronauts inside it are in free fall.

Explain why this makes the astronauts feel **weightless**.

.....

 [1]

- (b) (i) Calculate the value of the gravitational field strength g at the height of the ISS above the Earth.

$g = \dots\dots\dots \text{N kg}^{-1}$ [3]

- (ii) The speed of the ISS in its orbit is 7.7 km s^{-1} . Show that the period of the ISS in its orbit is about 90 minutes.

[2]

Question 4 continues on page 12

Turn over



(c) Use the information in (b)(ii) and the data below to show that the root mean square (r.m.s.) speed of the air molecules inside the ISS is approximately 15 times smaller than the orbital speed of the ISS.

- molar mass of air = $2.9 \times 10^{-2} \text{ kg mol}^{-1}$
- temperature of air inside the ISS = 20°C

[3]

- (d) The ISS has arrays of solar cells on its wings. These solar cells charge batteries which power the ISS. The wings always face the Sun.

Use the data below and your answer to (b)(ii) to calculate the **average** power delivered to the batteries.

- The total area of the cells facing the solar radiation is 2500 m^2 .
- 7% of the energy of the sunlight incident on the cells is stored in the batteries.
- The intensity of solar radiation at the orbit of the ISS is 1.4 kW m^{-2} outside of the Earth's shadow and zero inside it.
- The ISS passes through the Earth's shadow for 35 minutes during each orbit.

average power = ... W [4]

3 This question is about a space probe which is in orbit around the Sun.

(a) Define **gravitational potential energy** of an object at a point in a gravitational field.

.....
 [1]

(b) The space probe has mass 810 kg. The orbital radius of the space probe is 1.5×10^{11} m. The orbital period of the space probe around the Sun is 3.16×10^7 s. The mass of the Sun is 2.0×10^{30} kg.

(i) Show that the magnitude of the gravitational potential energy of the space probe is about 7×10^{11} J.

[2]

(ii) Show that the kinetic energy of the space probe is half the value of your answer to (b)(i).

[3]

(iii) Calculate the total energy of the space probe.

total energy = ... J [1]

- (c) The power source for the instrumentation on board the space probe is plutonium-238, which provides 470 W initially.

Plutonium-238 decays by α -particle emission with a half-life of 88 years.
The kinetic energy of each α -particle is 8.8×10^{-13} J.

- (i) Calculate the number N of plutonium-238 nuclei needed to provide the power of 470 W.

$N = \dots\dots\dots$ [3]

- (ii) Calculate the power P still available from the plutonium-238 source 100 years later.

$P = \dots\dots\dots$ W [3]

14-MARK QUESTIONS

1 question in this booklet



22

(a) A satellite in a geostationary orbit around the Earth appears to remain at the same point in the sky when viewed from the ground.

(i) State **one** condition required for an orbit to be geostationary.

.....
 [1]

(ii) Calculate the orbital radius of the geostationary satellite. The mass of the Earth is 6.0×10^{24} kg.

orbital radius = ... m [3]

(b) A satellite of mass m is in a circular orbit around a planet of mass M . The radius of the orbit from the centre of the planet is r .

The gravitational potential V_g at a point a distance r from the centre of the planet is given by the equation

$$V_g = -\frac{GM}{r}.$$

(i) By considering the cause of the centripetal force on the satellite, show that the kinetic energy of the satellite is equal to half the magnitude of its gravitational potential energy.

[2]

- (ii) A tiny satellite of mass 1.0 kg is to be launched from rest from the surface of the Earth into a low Earth orbit. The gravitational potential at any point in this orbit is -56 MJ kg^{-1} .

The value of the gravitational potential at the Earth's surface is -63 MJ kg^{-1} .

Show that the satellite must gain more than 30 MJ of **total** energy to achieve and remain in orbit.

[2]

- (c)* Large satellites are often launched by rockets from sites near the equator. The rotation of the Earth increases the initial kinetic energy of the rocket and satellite.

A new strategy is to launch using a smaller rocket from a high flying aircraft.

Using the information in (b)(ii) and the data below, evaluate the advantages and limitations of this strategy. Use calculations to support your evaluation.

Rotational speed at the equator	460 m s^{-1}	Typical aircraft operating altitude	10,000 m
		Aircraft cruise velocity (relative to the ground)	230 m s^{-1}

[6]

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

Additional space if required

.....

.....

.....

.....

.....

15-MARK QUESTIONS

1 question in this booklet



23 Algol is a triple-star system, with stars Aa1, Aa2 and Aa3 orbiting each other. This triple-star is 90 light-years from the Earth.

(a) Here is some data on the star Aa1.

- radius = $(1.90 \pm 0.14) \times 10^9 \text{ m}$
- mass = $(6.31 \pm 0.42) \times 10^{30} \text{ kg}$.

Calculate the gravitational field strength g at the surface of Aa1 to **3** significant figures. Include the absolute uncertainty in your answer. Assume that the other stars of the system exert negligible gravitational force on Aa1.

$$g = \dots\dots\dots \pm \dots\dots\dots \text{ N kg}^{-1} \text{ [4]}$$

(b) The table shows some data about the three stars of Algol.

Star	Luminosity of star / $L_{\odot}$	Surface temperature of star / K
Aa1	182	13 000
Aa2	6.92	4500
Aa3	10.0	7500

The luminosity of each star is in terms of the solar luminosity $L_{\odot}$.

(i) Define the **luminosity** of a star.

.....
 [1]

(ii) Use Stefan's law to determine the ratio $\frac{\text{radius of star Aa2}}{\text{radius of star Aa3}}$.

$$\text{ratio} = \dots\dots\dots [2]$$

- (iii) Use Wien's displacement law to explain which star would have the **longest** wavelength at the peak intensity of the emitted electromagnetic radiation.

.....

 [2]

- (iv) Suggest how an astronomer using just an optical telescope can deduce that the three stars of Algol have different surface temperatures.

.....
 [1]

- (v) The light from each star passing through a diffraction grating shows an absorption line spectrum.

Explain how a specific absorption line is produced in this type of spectrum in terms of **photons** and **electrons**.

.....

 [3]

- (c) The Aa1 star could evolve into a black hole.

State **two** ways in which the black hole would differ from the Aa1 star.

1.

 2.

 [2]



16-MARK QUESTIONS

1 question in this booklet



- 17 (a) Phobos is one of the two moons orbiting Mars. Fig. 17.1 shows Phobos and Mars.

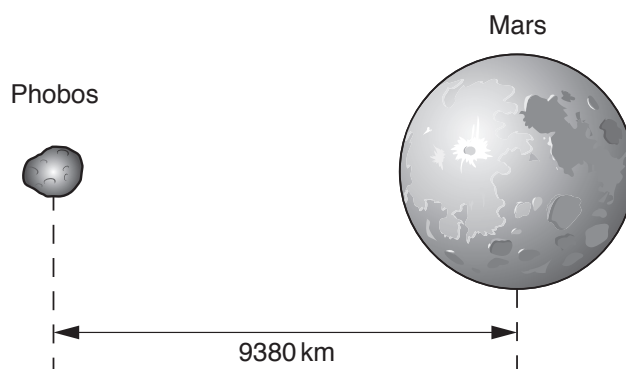


Fig. 17.1

The orbit of Phobos may be assumed to be a circle. The centre of Phobos is at a distance 9380 km from the centre of Mars and it has an orbital speed $2.14 \times 10^3 \text{ m s}^{-1}$.

- (i) On Fig. 17.1, draw an arrow to show the direction of the force which keeps Phobos in its orbit. [1]
- (ii) Calculate the orbital period T of Phobos.

$T = \dots\dots\dots \text{ s}$ [2]

- (iii) Calculate the mass M of Mars.

$M = \dots\dots\dots \text{ kg}$ [3]

- (b) The gravitational field strength at a distance r from the centre of Mars is g .

The table below shows some data on Mars.

$g/\text{N kg}^{-1}$	r/km	$\lg (g/\text{N kg}^{-1})$	$\lg (r/\text{km})$
1.19	6 000	0.076	3.78
0.87	7 000		
0.67	8 000	-0.174	3.90
0.53	9 000	-0.276	3.95
0.43	10 000	-0.367	4.00

- (i) Complete the table by calculating the missing values.

[1]

- (ii) Fig. 17.2 shows the graph of $\lg (g/\text{N kg}^{-1})$ against $\lg (r/\text{km})$.

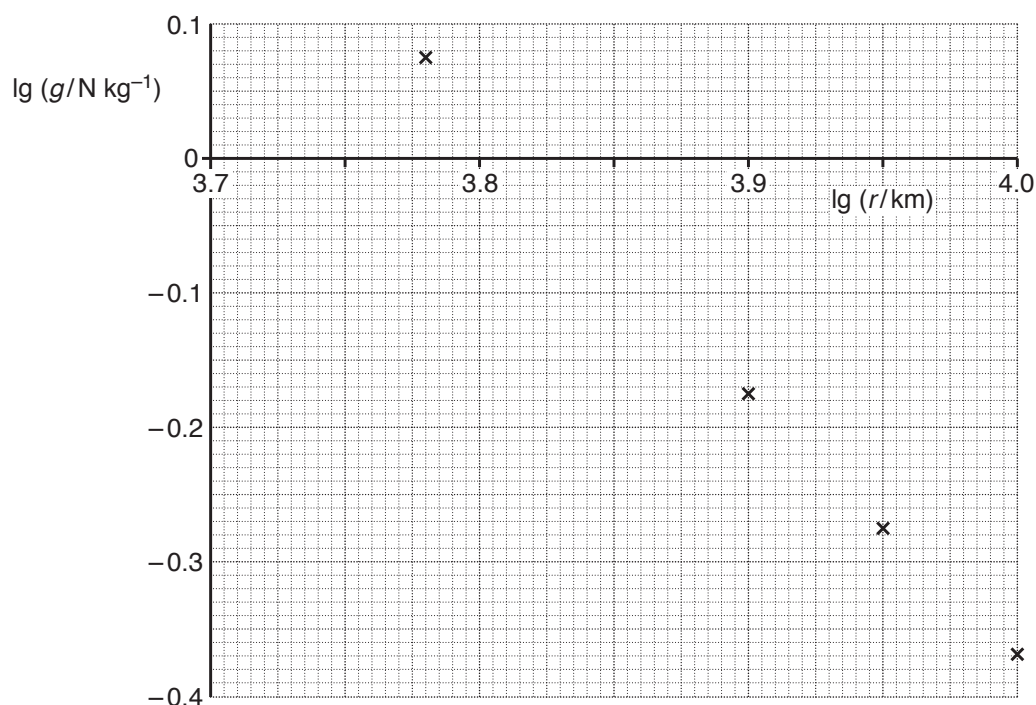


Fig. 17.2

- 1 Plot the missing data point on the graph and draw the straight line of best fit.

[2]

- 2 Use Fig. 17.2 to show that the gradient of the straight line of best fit is -2 .

[1]

- 3 Explain why the gradient of the straight line of best fit is -2 .

[2]

- (c) In July 2018, the closest distance between the centre of Mars and the centre of Earth will be 5.8×10^{10} m.

Fig. 17.3 shows the variation of the **resultant** gravitational field strength g between the two planets with distance r from the centre of the **Earth**.

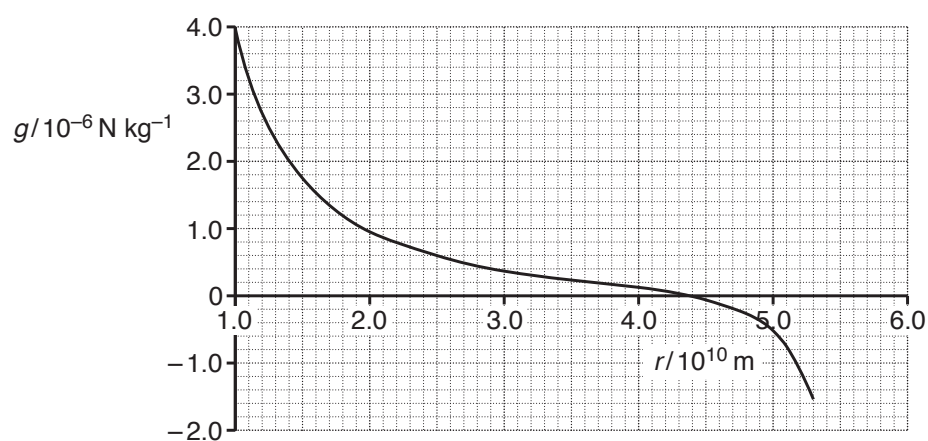


Fig. 17.3

- (i) Explain briefly the overall shape of the graph in Fig. 17.3.

.....

.....

.....

.....

..... [2]

- (ii) Use the value of r when $g = 0$ from Fig. 17.3 to determine the ratio

$$\frac{\text{mass of Earth}}{\text{mass of Mars}}.$$

$$\frac{\text{mass of Earth}}{\text{mass of Mars}} = \dots\dots\dots [2]$$



MARK SCHEMES

official OCR mark schemes



1	B	1	
----------	----------	----------	--



9	C	1	
---	---	---	--



2	B		1	
----------	----------	--	----------	--



13	C		1	
----	---	--	---	--



6	D	1	
---	---	---	--



11	B	1	
----	---	---	--



5	B	1	
---	---	---	--



7	B	1	
---	---	---	--



11	C	1	
----	---	---	--



11	C		1	
----	---	--	---	--



15	B	1	
	Total	15	

8

SECTION B

General rule: For substitution into an equation, allow any subject - unless stated otherwise in the guidance

Question	Answer	Marks	Guidance
----------	--------	-------	----------



1	C	1	
---	---	---	--



7	B	1	
---	---	---	--



11	D	1	
----	---	---	--



14	C	1	
----	---	---	--



8	B	1	
----------	----------	----------	--



9	A	1	
---	---	---	--



21		Level 3 (5–6 marks) Detailed explanation of dark lines. Differences between lines discussed with explanation. Correct conclusion with reasoning <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Some explanation of dark lines with some differences between lines Or Detailed description of dark lines Or Detailed description of the differences in line <i>There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Either Limited explanation of dark lines or a difference in lines given with an unsupported conclusion or no conclusion at all	B1 x 6	Indicative scientific points may include: Dark lines • Dark lines show wavelengths absorbed • Star produces a continuous spectrum • Atmosphere of star absorbs light • Photons are absorbed by electrons increasing/moving ‘up’ energy levels • Energy of photons match differences in energy levels of atoms • Light is re-emitted by atoms in star atmosphere • Light is re-emitted in random directions Differences (number of lines and intensities) • Tau Ceti has extra lines/Vega has fewer lines • Lines in common are different intensities (stronger/weaker) • Tau Ceti has more elements • Different proportions of hydrogen Analysis/conclusion • Vega is younger/Tau Ceti is older • Tau Ceti has had more time to fuse heavier elements
----	--	---	--------	---

Question			Answer	Mark	Guidance
			<i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i> 0 marks <i>No response or no response worthy of credit.</i>		• Tau Ceti has a lower proportion of hydrogen because it has been fusing/using it for longer • Accept that idea Vega may be older than Tau Ceti if Tau Ceti has more mass
			TOTAL	6	

23	(a)		$V_{(g)} = -\frac{GM}{r}$	B1	
	(b)	(i)	KE = $\frac{1}{2}mv^2$ and GPE = GMm/r $\frac{1}{2}mv^2 = GMm/r$ then a valid step to $v = \sqrt{(2GM/r)}$	C1 A1	Allow $m = 1$ (kg) if clearly defined
		(ii)	$(v^2 = 2 \times 6.67 \times 10^{-11} \times 0.131 \times 10^{23} / 1.19 \times 10^6)$ $v = 1200 \text{ (m s}^{-1}\text{)}$	A1	Answer to 3.s.f. is 1210
		(iii)	Mercury has a higher escape velocity than Pluto (ORA) Mercury is closer to sun and Mercury is hotter (ORA) Molecules on Mercury (are more likely to) have speed higher than the escape velocity	B1 M1 A1	Allow a supporting calculation (speed is about 4.2 km s^{-1}) Allow 'required speed' for 'escape velocity' Allow 'fast enough to escape'
			Total	7	



1	(a)	(i)	X marked on orbit at closest point to Mars	B1	Horizontal line through centre of X must pass through or touch the label 'Mars' Allow a single dot/circle marked on the orbit																														
		(ii)	orbits in an <u>ellipse</u> / orbit is <u>elliptical</u> with (COG of) Mars at one focus	B1 B1	Allow a general statement even if not applied to MAVEN eg (all) orbits are elliptical Ignore references to Sun or other planets Not the Sun at one focus																														
	(b)	(i)	$T^2 \propto r^3$ Correct calculations involving at least two sets of data which lead to a (reasonably) constant value	C1 A1	Not $T^2 = r^3$ Allow $T^2/r^3 = (\text{any}) \text{ constant}$ or $T^2 = (\text{any}) \text{ constant} \times r^3$ Allow $T_1^2 / T_2^2 = r_1^3 / r_2^3$ May be inferred from a subsequent calculation For example, T^2/r^3 (or r^3/T^2) calculated correctly at least twice: Allow a constant value calculated for one set of data and then applied to at least one other object Calculations do not need corresponding names of objects Ignore number of sf; ignore any incorrect calculations Ignore statements about whether or not Kepler's 3 rd Law applies Values below are for benefit of markers, POTs removed <table><tr><th>Object</th><th colspan="2">T^2/r^3</th><th colspan="2">r^3/T^2</th></tr><tr><td></td><td>$T(hr)$</td><td>$T(s)$</td><td>$T(hr)$</td><td>$T(s)$</td></tr><tr><td>MAVEN</td><td>7.4</td><td>9.6</td><td>1.4</td><td>10.5</td></tr><tr><td>Phobos</td><td>7.1</td><td>9.3</td><td>1.4</td><td>10.8</td></tr><tr><td>Deimos</td><td>7.4</td><td>9.6</td><td>1.4</td><td>10.4</td></tr><tr><td>Areostationary</td><td>7.8</td><td>10.1</td><td>1.3</td><td>9.9</td></tr></table>	Object	T^2/r^3		r^3/T^2			$T(hr)$	$T(s)$	$T(hr)$	$T(s)$	MAVEN	7.4	9.6	1.4	10.5	Phobos	7.1	9.3	1.4	10.8	Deimos	7.4	9.6	1.4	10.4	Areostationary	7.8	10.1	1.3	9.9
Object	T^2/r^3		r^3/T^2																																
	$T(hr)$	$T(s)$	$T(hr)$	$T(s)$																															
MAVEN	7.4	9.6	1.4	10.5																															
Phobos	7.1	9.3	1.4	10.8																															
Deimos	7.4	9.6	1.4	10.4																															
Areostationary	7.8	10.1	1.3	9.9																															

Question			Answer	Mark	Guidance
1	b	(ii)	(MAVEN needs) to see the whole planet / atmosphere or not just part of the planet / atmosphere (MAVEN needs) to be in / near to the atmosphere	B1 B1	Ignore comments about potential collisions / mass / orbital period / speed / direction Allow (if placed in an areostationary orbit, then) MAVEN would always orbit above the same place / it could only see one location / it could not see multiple locations / it could not see (atmosphere at) the poles / it could only see part of the (atmosphere of) Mars Allow (if placed in an areostationary orbit, MAVEN's orbital radius would be large that) it would not pass through the atmosphere / it could not analyse the atmosphere Not MAVEN is too close to see the atmosphere properly Note: Atmosphere does not need to be seen to award first B1 Atmosphere must be mentioned somewhere in the response to award second B1
			Total	7	

24	(a)	(i)	distance between positions = 3.1 cm $2p = 3.1/2$ (any subject) $p = 0.78$ arc seconds	M1 M1 A0	Allow distance in the range 2.9 to 3.2 cm
		(ii)	$(d = 1/p)$; $d = 1/0.8$ or 1.25 (pc) $d = 1.25 \times 3.26$ $d = 4.1$ (ly)	C1 A1	Allow: their value for p Possible ECF from (a)(i) Answer is 4.2 using 0.78 arc seconds
	(b)	(i)	$F = GMm/r^2$ $F = G \times (2.0 \times 10^{41})^2 / (1.4 \times 10^{23})^2$ force = 1.4×10^{26} (N)	C1 A1	Note the mark is for substitution, value of G is not required Ignore: minus sign Allow 1 mark for 1.4×10^4 N ;use of mass of star instead of mass of galaxy.
		(ii)	density = $10^{11} \times 2.0 \times 10^{30} / 2.7 \times 10^{69}$ density = 7.4×10^{-29} (kg m ⁻³)	M1 A0	
		(iii)	Any reasonable answers questioning model such as observed average distance may be different, average mass may be wrong etc.	B1	e.g. black holes, dark energy/matter, expanding universe
			Total	8	



20	(a)	(i)	Straight symmetrical radial field lines and correct direction of field	B1	Ignore field lines inside the Earth
		(ii)	X and Y labelled which should be an equal distance away from the centre of the Earth	B1	Note Judge by eye Allow X and Y both on the surface of the Earth

	(b)*	Level 3 (5–6 marks) Clear description and correct calculations leading to value of total energy (must include the negative sign) <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Some description and some correct calculations or Correct calculations (including the negative sign) <i>There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Limited description or Limited calculations <i>The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.</i> 0 marks No response or no response worthy of credit.	B1×6	Indicative scientific points may include: Description - Orbit above the equator / equatorial orbit - Orbit from west to east/same direction of orbit as Earth's rotation - Orbital period is 24 hours / 1 (sidereal) day / 23hrs 56mins (4 s) - Orbit is circular / above the same point on the Earth Calculation $E = (-) \frac{GMm}{r}$ $E = \frac{6.67 \times 10^{-11} \times 5.97 \times 10^{24} \times 2500}{4.22 \times 10^7} = (-) 2.4 \times 10^{10} \text{ J}$ $v = \frac{2\pi r}{T} = \omega r$ $v = \frac{2\pi \times 4.22 \times 10^7}{24 \times 3600} = 3.07 \times 10^3 \text{ m s}^{-1}$ $E = \frac{1}{2}mv^2$ $E = \frac{1}{2} \times 2500 \times [3.07 \times 10^3]^2 = 1.2 \times 10^{10} \text{ J}$ - Total energy = $-2.4 \times 10^{10} + 1.2 \times 10^{10} = -1.2 \times 10^{10} \text{ J}$ - Allow full credit for algebraic proof using $\frac{GMm}{r^2} = \frac{mv^2}{r}$, $E = (-) \frac{GMm}{r}$, $E = \frac{1}{2}mv^2$ and total energy = KE + PE Allow higher order answers in terms of Lagrange's Identity
		Total	8	

22	(a)	(i)	$T_{\text{asteroid}}^2 = 3.5^3$ $T = 6.5 \text{ (yr)}$	C1 A1	Accept substitution of given formula with AU in metres (giving time in seconds) Answer to 3sf is 6.55 (yr)
		(ii)	$R = 3.5 \text{ AU} = 3.5 \times 1.5 \times 10^{11} = 5.3 \times 10^{11} \text{ (m)}$ $v = 2\pi R/T = 16 \text{ (kms}^{-1}\text{)}$ $KE = \frac{1}{2}mv^2 = 1.3 \times 10^9 \text{ J}$	C1 C1 A1	ECF from (a)(i) for T Note: $v = R/T$ is XP Allow ECF from v Allow $1.2 \times 10^9 \text{ (J)}$ if no premature rounding in calculation Answer is $1.26 \times 10^9 \text{ (J)}$ to 3sf Alternative method $mv^2/r = GMm/r^2 \text{ (C1)}$ $\frac{1}{2}mv^2 = m \times \frac{1}{2}GM/r = \frac{1}{2} \text{ of GPE (C1)}$ $= 1.3 \times 10^9 \text{ J from graph (A1)}$
	(b)	(i)	Potential difference from graph = $0.9 - 0.25 = 0.65 \text{ GJ kg}^{-1}$ GPE = mass $\times$ potential difference = 6.5 GJ	C1 A1	If calculated value is 0.89-0.25 Ignore sign Allow ECF from the graph
		(ii)	The Sun is at one focus	B1	
			TOTAL	8	

23	(a)*	Level 3 (5–6 marks) Correct calculations for radius and temperature range or distance or intensity for Earth-like temperature within given distance range, with clear explanation. <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Radius calculated or at least one temperature of planet calculated and some explanation. <i>There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Some explanation and an attempt at least one calculation. <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i> 0 marks No response or no response worthy of credit.	B1× 6	Use level of response annotation in RM Assessor, e.g. L2 for 4 marks, L2^ for 3 marks etc. Indicative scientific points may include: Explanation • TRAPPIST-1 is cooler than the Sun • The planets are closer to TRAPPIST-1 • Possible for temperature on planets to be like Earth • For life to exist, temperature is not the only factor • $L = 4\pi r^2 \sigma T^4$ (Any subject) Calculations • Calculation of 'constant' for Earth: $4(.19) \times 10^5$ • For inner-most planet, $T = 430$ K • For outer-most planet, $T = 180$ K • Calculation of distance for $T = 290$ K, i.e. 3.4×10^9 (m) • There must therefore be a planet with temperature similar to that of the Earth • $L = 4\pi r^2 \sigma T^4$ used to calculate radius of TRAPPIST-1 • Radius of TRAPPIST-1 is 8.5×10^7 (m) or L/T^4 is smaller for TRAPPIST-1 • Comparison of calculated intensities at extreme distances around TRAPPIST-1 to intensity at Earth
----	------	--	-------	--

Question			Answer	Marks	Guidance
	(b)	(i)	$T^2 = \frac{4\pi^2}{GM} r^3$	B1	
		(ii)	$86400^2 = (4\pi^2/6.0 \times 10^{24} \times 6.67 \times 10^{-11}) r^3$ (Any subject) radius = 4.23×10^7 (m)	C1 A1	
			Total	9	



Question	Answer	Marks	Guidance
----------	--------	-------	----------



23	a		$G \frac{Mm}{r^2} = \frac{mv^2}{r}$ or $G \frac{Mm}{r^2} = mr\omega^2$ $v = \frac{2\pi r}{T}$ or $\omega = \frac{2\pi}{T}$ Substitution and manipulation to give $T^2 = \frac{4\pi^2}{GM} r^3$ (with $\frac{4\pi^2}{GM}$ is constant)	M1 M1 A1	Allow any subject
	b	i	$\left(\frac{168}{365}\right)^2 = \left(\frac{r}{1.50 \times 10^{11}}\right)^3$ distance = 8.9×10^{10} (m)	C1 A1	Ignore calculation of arithmetic mean of data in question Allow substitution into $T^2 = \frac{4\pi^2}{GM} r^3$ Ignore units for subs into Kepler's law NOT 8.95 or $9(.0) \times 10^{10}$ (m) (mean calculated)
		ii	$(\Delta GPE = \Delta KE)$ $GMm \left(\frac{1}{4.20 \times 10^{10}}\right)$ or $GMm \left(\frac{1}{1.37 \times 10^{11}}\right)$ (change in KE =) $6.67 \times 10^{-11} \times 2.0 \times 10^{30} \times m \left(\frac{1}{4.20 \times 10^{10}} - \frac{1}{1.37 \times 10^{11}}\right)$ change in kinetic energy = 4.6×10^{11} (J)	C1 C1 A1	Allow this mark without the m Allow this mark without the m Allow 2 marks for 2.2×10^9 ; ΔV calculated Ignore sign
		iii	Description of reasonable effect of Earth has been ignored / work done by fuel (during lift off) / idea that atmosphere has been ignored previously	B1	
			Total	9	



22	(a)	(i)	<u>KE</u> is conserved (as well as momentum)	B1	Allow: No <u>KE</u> lost
		(ii)	Attempt at conservation of momentum in x- or y- direction Correct expression of conservation of momentum in x- or y- direction / correct determination for velocity of Y of 55(3) m s⁻¹ $p = 3.7 \times 10^{-24} \text{ (kg m s}^{-1}\text{)}$	C1 Allow confusion of sin and cos at this stage Allow attempt at conservation of KE C1 Allow any subject e.g. $p \cos(25^\circ) + m \times 258 \cos(65^\circ) = m \times 610$ or $p \sin(25^\circ) = m \times 258 \sin(65^\circ)$ or $(p)^2 + (m \times 258)^2 = (m \times 610)^2$ or $\frac{1}{2} mv^2 + \frac{1}{2} m (258)^2 = \frac{1}{2} m (610)^2$ A1 Answer is $3.67 \times 10^{-24} \text{ (kg m s}^{-1}\text{)}$ to 3 sf	



Question	Answer	Marks	Guidance
(b)*	Level 3 (5–6 marks) Clear explanation and correct calculation. <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Some explanation and limited calculation, or limited explanation and correct calculation. <i>There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Limited explanation and missing or incomplete calculation. <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i> 0 marks No response (NR) or no response worthy of credit (0).	B1x6	Indicative scientific points may include: Explanation - At a certain temperature all atoms have the same <u>average</u> kinetic energy - Helium behaves as an ideal gas $E_K = \frac{3}{2} kT$ - Mean / r.m.s speed of atoms is less than the escape velocity - Atoms have range of speeds / velocity or mention of Maxwell-Boltzmann distribution - Faster atoms have escaped the Earth (over long period of time) - Earth was significantly hotter in the (ancient) past Calculation $T = 283 \text{ K}$ $\frac{1}{2} m \overline{c^2} = \frac{3}{2} kT$ $c_{r.m.s.} = \sqrt{\frac{3kT}{m}}$ $c_{r.m.s.} = 1.3 \text{ km s}^{-1}$
	Total	10	



Question	Answer	Marks	Guidance
3 (a) (i)	(For circular orbit) <u>centripetal</u> force provided by <u>gravitational</u> force (of attraction) (Gravitational / centripetal) force is along line joining stars which must therefore be diameter of circle (AW)	M1 A1	
(a) (ii)	$T = 20.5 \times 86400 (= 1.77 \times 10^6 \text{ s})$ and $R = 1.8 \times 10^{10} \text{ (m)}$ $m = 16 \times \pi^2 \times (1.8 \times 10^{10})^3 / G \times (20.5 \times 86400)^2$ giving $m = 4.4 \times 10^{30}$ so $m = 2.2 M_{\odot}$	C1 C1 A1	values of T and R scores first mark; both incorrect 0/3 correct substitution allowing π^2 and G $m = 16 \times 9.87 \times 1.8^3 \times 10^{30} / 6.67 \times 10^{-11} \times 1.8^2 \times 10^{12}$ using 2R gives $35.2 \times 10^{30} = 17.6 M_{\odot}$ or using T = 1 day gives $1850 \times 10^{30} = 930 M_{\odot}$ award 2/3
(a) (iii)	$v = 2\pi R/T = 2 \times 3.14 \times 1.8 \times 10^{10} / 1.8 \times 10^6$ (giving $v = 6.3$ or 6.4×10^4) $\Delta\lambda = (v/c)\lambda = (6.3/3) \times 10^{-4} \times 656 = 0.14 \text{ (nm)}$	C1 A1	do not penalise repeated error for R or T ecf for incorrect v, gives $\Delta\lambda = v \times 2.2 \times 10^{-6}$ $\Delta\lambda = 0.28$ for 2R; $\Delta\lambda = 2.9$ for 1 day and $\Delta\lambda = 5.7$ for both incorrect
(b) (i)	Two circles with centres at CoM with radii in ratio 4 :1 CoM at surface of larger star on line joining stars	B1	allow diameter of m orbit through CoM as $44 \pm 10 \%$ for example; full reasonable circles required; ignore arrows;
(b) (ii)	Same period/(angular) frequency of stars but longer path for smaller star/AW or $v = 2\pi R/T$ or $v \propto R$ or stars stay at opposite ends of line through CoM	B1 B1	any arguments using $F = mv^2/r$ score zero
	Total	10	

Question	Answer	Marks	Guidance
----------	--------	-------	----------

23	(a)	(i)	X at closest point on orbit to the Sun	B1	Allow X on the orbit to the <u>left</u> of the Sun
		(ii)	(When the asteroid orbits the sun a) line segment joining the asteroid to the Sun sweeps out equal areas in equal time (intervals) Longer distance (in orbit for the same time)	B1 B1	Allow this mark on diagram (no labelling required) Allow 'equal area swept in same time'
	(b)	(i)	Work done per unit mass to move an object from infinity (to that point)	B1	Not 'work done on 1 kg'
		(ii)	Manipulation of $V_{(g)} = (-) GM/r$	B1	
		(iii)	gradient = $(-)30.4$ or equivalent working candidate's gradient or expression = $6.67 \times 10^{-11} \times M$ and M calculated correctly from that gradient $M = 4.6 \times 10^{11}$ (kg)	C1 C1 A0	Allow ± 2 Possible ECF from incorrect gradient Allow any subject
	(c)		Method 1: Evidence of 2.3×10^{-3} and 600^{-1} or $(2.3 \times 10^{-3})^{-1}$ and 600 $\frac{1}{2} v^2 = 6.67 \times 10^{-11} \times 4.6 \times 10^{11} \times (2.3 \times 10^{-3} - 600^{-1})$ $v = 0.20$ (m s ⁻¹) Method 2: Evidence of 7.0×10^{-2} and 5.1×10^{-2} from graph $\frac{1}{2} v^2 (= \Delta V_{(g)}) = 7.0 \times 10^{-2} - 5.1 \times 10^{-2}$ $v = 0.19$ (m s ⁻¹)	C1 C1 A1 (C1) (C1) (A1)	Possible ECF from (b)(iii) for either value of GM or M Allow $\frac{1}{2} v^2 = 30 \times (2.3 \times 10^{-3} - 600^{-1})$ Note answer can be 0.19 or 0.20 or 0.2 m s ⁻¹ Note answer can be 0.19 or 0.20 or 0.2 m s ⁻¹ Allow correct use of one piece of data arriving at a value for v for 1 mark max
			Total	10	

23	(a)	(i)	$= 1 \div 0.00097$ $= 1000$ parsecs	A1	1030 to 3sf
		(ii)	$= 0.00097 \div 7.5 \times 10^{-3} (\times 100\%)$ $= 13\%$	C1 A1	NOT half of the precision here (reference specification) Accept 1 sig fig value 10% Unrounded answer is 12.93... %
	(b)	(i)	Use of $KE_{\text{mean}} = \frac{3}{2} kT = \frac{3}{2} \times k \times 4.0 \times 10^6$ $= \frac{3}{2} \times 1.38 \times 10^{-23} \times 4 \times 10^6$ $= 8.3 \times 10^{-17} \text{ J.}$	C1 A1	Allow k Unrounded answer is $8.28 \dots \times 10^{-17}$
		(ii)	$= -2.3 \times 10^{-16} + 8.3 \times 10^{-17}$ $= -1.5 \times 10^{-16} \text{ J.}$	B1	Allow use of 10^{-16} J from stem to give $-1.3 \times 10^{-16} \text{ J}$ Reject response without negative sign

Question			Answer	Mark	Guidance
		(iii)	selection of GMm/r Substitution of values for M, m and energy and rearrangement $3.2 \times 10^{10} \text{ m}$ e.g. $(-) \frac{GMm}{r} = (-) 1.5 \times 10^{-16}$ $r = \frac{6.67 \times 10^{-11} \times 1.1 \times 10^{31} \times 6.6 \times 10^{-27}}{1.5 \times 10^{-16}}$ $= 3.2 \times 10^{10} \text{ m}$	C1 C1 A1	Allow ECF from (b)(ii) NB Use of values in stem gives 3.7×10^{10}
		(iv)	Reference to Boltzmann distribution / AW OR Some particles will have greater kinetic energies / lower masses	B1	
			TOTAL	10	



20	(a)		$E_k = \frac{1}{2} mv^2$ <u>and</u> $p = mv$ (Correct manipulation leading to) $E_k = \frac{1}{2} p^2/m$	M1	Allow: any subject
				A1	Allow: $E_k = p^2/(2m)$
	(b)	(i)	From $t = 0$ to $t = 2.0$ s: a non-zero horizontal line From $t = 2.0$ to $t = 3.5$ s: line showing $v = 0$ From $t = 3.5$ to $t = 4.0$ s: non-zero horizontal line showing v is <u>opposite</u> in direction <u>and</u> magnitude larger than that of line drawn at $t = 0$ to $t = 2.0$.	B1 B1 B1	Judgement by eye
		(ii)	KE is constant. GPE increases linearly / proportional to t	B1 B1	Allow: 'at constant rate' for 'linear' Not: unqualified 'constantly'
		(iii)1	$V^2 = 0.80^2 + 2 \times 9.81 \times 0.40$ $V = 2.9 \text{ (m s}^{-1}\text{)}$	C1 A1	Allow 1 mark for $(2 \times 9.81 \times 0.40)^{1/2} = 2.8 \text{ (m s}^{-1}\text{)}$
		(iii)2	$F = 0.12 \times 2.9/0.025$ $F = 14 \text{ (N)}$	C1 A1	Possible ECF from (iii)1 Note: use of 2.8 m s^{-1} gives $F = 13(.44 \text{ N})$ Note: $1.4 \times 10^1 \text{ (N)}$ scores 1 mark
			Total	11	

21	(a)		$\omega^2 = k/m$ or 60/0.080 or $\omega^2 = 750$ $T = 2\pi/27.39$ or $T = 0.2295$ (s) $t = \frac{1}{4} \times 0.2295$ $t = 0.057$ (s)	C1 C1 C1 A1	Allow correct algebraic expression for T Allow incorrect value for omega Allow incorrect value of T
	(b)	(i)	$E = \frac{1}{2}kx^2$ or $E = mgh$ or $0.080 \times 9.81 \times 0.20$ or $\frac{1}{2} \times 60 \times x^2$ $0.080 \times 9.81 \times 0.20 = \frac{1}{2} \times 60 \times x^2$ $x = 0.072$ (m)	C1 C1 A1	
		(ii)1	Time of flight is independent of speed/AW Because distance of fall is the same and initial velocity vertically is zero / velocity is horizontal at X	B1 B1	Allow algebraic answers that assume initial vertical velocity is zero/velocity is horizontal at X.
		(ii)2	D increases as speed at X increases because the time of flight is constant/AW D is directly proportional to speed at X	M1 A1	Allow $d = vt$ idea “ D is directly proportional to speed at X because the time of flight is constant” scores 2.
			Total	11	

Question	Answer	Marks	Guidance
----------	--------	-------	----------



1	(a)		$g = GM/r^2$ $g = \frac{6.67 \times 10^{-11} \times 4.87 \times 10^{24}}{(6\,050 \times 10^3)^2}$ $g = 8.87 \text{ (N kg}^{-1}\text{)}$	C1 Allow m for M Allow d or D or x or X or R for r C1 Full substitution needed Allow $r = 6\,050$ for this C1 mark A1 Allow a negative answer Answer must be to exactly 3sf for the A1 mark. Do not use the SF penalty for the paper here
	(b)	(i)	$a = \omega^2 r$ and $\omega = 2\pi / T$ or $a = v^2 / r$ and $v = 2\pi r / T$ Either $\omega = \frac{2\pi}{5830 \times 3600}$ or $v = \frac{2\pi \times 6050 \times 10^3}{5830 \times 3600}$ or $a = \frac{4\pi^2}{(5830 \times 3600)^2} \times 6050 \times 10^3$ $a = 5.42 \times 10^{-7} \text{ (m s}^{-2}\text{)}$	C1 Allow use of $T^2 = 4\pi^2 r^3 / (GM)$ and $v = 2\pi r / T$ C1 $\omega = 2.99 \times 10^{-7} \text{ (rad s}^{-1}\text{)}$ $v = 1.81 \text{ (m s}^{-1}\text{)}$ $a = \omega^2 r = (2.99 \times 10^{-7})^2 \times 6050 \times 10^3$ $a = v^2 / r = 1.81^2 / (6050 \times 10^3)$ Do not allow incorrect or omitted conversion of T A1 Allow answer given to 2sf Allow any answer which rounds to 5.4×10^{-7} Do not penalise incorrect km conversion (giving $a = 5.42 \times 10^{-10}$) if already penalised in (a)

[illegible]

3	(a)	(motion of truck) moves/spins coil/wire in magnetic field (rate of) change in flux linkage (causes induced e.m.f. driving a current through the battery) Any one from: • <u>work done</u> by gravity / weight (reduces GPE) • <u>work done</u> on charge by magnetic field (transfer to electric energy) • <u>work done</u> by charge passing through battery (transfer to chemical energy)	B1 B1 B1	Allow (motion of truck) moves/spins magnet in coil of wire or description of relative motion between coil and magnet/magnetic field Allow lines of flux are cut (inducing an emf)
3	(b)	Any 3 from: • (internal energy is) sum of kinetic and potential energy of particles (in the wax) • increase in temperature in solid wax corresponds to particles increasing their kinetic energy (but potential energy remains constant) • change of state corresponds to particles increasing their potential energy • increase in temperature in liquid wax corresponds to particles increasing their kinetic energy (but potential energy remains constant)	B1x3	Accept KE for kinetic energy and PE for potential energy throughout Allow $KE \propto \text{temperature}$ Allow during change of state work is being done against intermolecular attractive forces Note only award KE mark once unless one comment is clearly for solid wax and the other for liquid wax i.e. before and after melting

3	(c)	Level 3 (5–6 marks) Clear correct calculations, including efficiency, for both sand and wax and clear quantitative discussion comparing the two methods or limited quantitative discussion and discussion of pros/cons of both methods <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Some correct calculations for both sand and wax including a specific heat capacity calculation OR Limited calculation(s) for sand and/or wax and some discussion of pros/cons <i>There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Limited calculation(s) OR Limited discussion <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i> 0 marks <i>No response or no response worthy of credit.</i>	6 × B1	Use level of response annotations in RM Assessor No ticks Indicative scientific points may include: Calculations • $\Delta GPE = mg\Delta h \approx 1 \times 9.81 \times 1000 = 9.8 \text{ kJ}$ • $\text{useful} = 0.7 \times 10 \text{ kJ} = 6.9 \text{ kJ}$ • $\Delta E = mc\Delta\theta = 1 \times 2.6 \times (51-18) = 86 \text{ kJ}$ • $\Delta E = mL = 1 \times 160 = 160 \text{ kJ}$ • $\Delta E = mc\Delta\theta = 1 \times 3.0 \times (70-51) = 57 \text{ kJ}$ • Total E for wax = 300 kJ • useful for wax = $0.95 \times 300 \approx 290 \text{ kJ}$ Discussion • Thermal system stores ~40 times as much energy per kg of material • GPE pros: readily available material; no new infrastructure required; energy stored in batteries can be directly released to the grid; energy can be stored indefinitely • GPE cons: requires mountainous terrain; slow response time • Thermal pros: high energy density; easily scaled up or automated; can be built in any location • Thermal cons: energy stored cannot readily be converted to electrical energy for the grid; limited storage time as wax cools
		Total	12	

4	(a)		There is no contact force between the astronaut and the (floor of the) space station (so no method of measuring / experiencing weight)	B1	Allow astronaut and the space station have same acceleration (towards Earth) / floor is falling (beneath astronaut)
	(b)	(i)	$M = 5.97 \times 10^{24}(\text{kg})$ or ISS orbital radius $R = 6.78 \times 10^6(\text{m})$ or $g \propto 1/r^2$ $(gr^2 = \text{constant so}) g \times (6.78 \times 10^6)^2 = 9.81 \times (6.37 \times 10^6)^2$ $g = 8.66 (\text{N kg}^{-1})$	C1 C1 A1	 or $g (= GM/R^2) = 6.67 \times 10^{-11} \times 5.97 \times 10^{24} / (6.78 \times 10^6)^2$ Allow rounding of final answer to 2 SF i.e. 8.7 (N kg ⁻¹)
		(ii)	$2\pi r/T = v$ or $T = 2 \times 3.14 \times 6.78 \times 10^6 / 7.7 \times 10^3$ $T = 5.5 \times 10^3 \text{ s } (= 92 \text{ min})$	M1 A1	ECF incorrect value of R from b(i)
	(c)		$\frac{1}{2}Mc^2 (\frac{1}{2}N_A mc^2) = \frac{3}{2}RT$ $c^2 = 3 \times 8.31 \times 293 / 2.9 \times 10^{-2} = 2.52 \times 10^5$ $\sqrt{c^2} = 500 (\text{m s}^{-1})$ $(= 7.7 \times 10^3 / 15)$	C1 C1 A1 A0	or $\frac{1}{2}mc^2 = \frac{3}{2}kT$ or $c^2 = 3kT/m$ or $c^2 = 3 \times 1.38 \times 10^{-23} \times 6.02 \times 10^{23} \times 293 / 2.9 \times 10^{-2} = 2.52 \times 10^5$ not $(7.7 \times 10^3 / 15) = 510 (\text{m s}^{-1})$
	(d)		power reaching cells $(= IA) = 1.4 \times 10^3 \times 2500 = 3.5 \times 10^6 \text{ W}$ power absorbed $= 0.07 \times 3.5 \times 10^6 = 2.45 \times 10^5 \text{ W}$ cells in Sun for $(92 - 35 =) 57$ minutes average power $= 57/92 \times 2.45 \times 10^5 = 1.5 \times 10^5 (\text{W})$	C1 C1 C1 A1	 mark given for multiplication by 0.07 at any stage of calculation $(90 - 35 =) 55$ minutes using $T = 90$ minutes ECF value of T from b(ii) $55/90 \times 2.45 \times 10^5 = 1.5 \times 10^5 (\text{W})$ using $T = 90$ minutes
			Total	13	

H556/03**Mark Scheme****November 2020**

Question	Answer	Marks	Guidance
----------	--------	-------	----------



3	(a)		GPE is the work done in bringing an object from infinity (to that point)	B1	Ignore any equations
	(b)	(i)	GPE = (-) GMm/r GPE = (-) $6.67 \times 10^{-11} \times 2 \times 10^{30} \times 810 / 1.5 \times 10^{11}$ GPE = (-) 7.2×10^{11} (J)	C1 C1 A0	Mark is for full substitution, including 6.67×10^{-11} for G
		(ii)	$v = 2\pi r/T = 2\pi \times 1.5 \times 10^{11} / 3.16 \times 10^7$ (= 29.8 km s ⁻¹) KE = $\frac{1}{2}mv^2 = 0.5 \times 810 \times (29.8 \times 10^3)^2$ KE = 3.6×10^{11} (J)	C1 M1 A1	Allow proof by algebraic method for full marks e.g. $mv^2/r = GMm/r^2$ so $mv^2 = GMm/r$ Therefore KE/GPE = $\frac{1}{2}mv^2 / (GMm/r) = \frac{1}{2}$
		(iii)	total energy = (-) ($7.2 \times 10^{11} - 3.6 \times 10^{11}$) total energy = (-) 3.6×10^{11} (J)	M1 A0	working must be shown; ECF (i) and (ii)
	(c)	(i)	$A = 470 / 8.8 \times 10^{-13} = 5.3 \times 10^{14}$ (Bq) $\lambda = \ln 2 / (88 \times 3.16 \times 10^7)$ (= 2.5×10^{-10} s ⁻¹) ($A = \lambda N$); N (= $5.3 \times 10^{14} / 2.5 \times 10^{-10}$) = 2.1×10^{24}	C1 C1 A1	Mark is for correct calculation of A (in Bq or decays per s) Mark is for correct working to give λ in s ⁻¹
		(ii)	$P = P_0 \exp(-\lambda t)$ $P = 470 \exp(-\ln 2 \times 100 / 88)$ $P = 210$ (W)	C1 C1 A1	Allow formula in terms of N or A Allow calculation in terms of N or A ; allow ECF for N or A
			Total	13	

7

H556/03

Mark Scheme

October 2021

Question	Answer	Marks	Guidance
----------	--------	-------	----------



22	a	i	Period equal to one day/24 hours/rotational period of Earth Or Rotation in same direction as the rotation of the Earth (on its axis) Or Equatorial orbit Or radius of orbit is approx 42 000 km Or height of orbit above Earth's surface is approx 36 000 km Or zero velocity relative to Earth's surface	B1	
		ii	Use of $T=3600 \times 24$ (or 86,400 from data book) Substitution into $T^2 = \frac{4\pi^2}{GM} r^3$ i.e. $(86400)^2 = (4\pi^2 / (G \times 6.0 \times 10^{24})) r^3$ $r = 4.2 \times 10^7$ (m)	C1 C1 A1	NOT 'is in the same place in the sky'
	b	i	$\frac{GMm}{r^2} = \frac{mv^2}{r}$ $\frac{1}{2}mv^2 = \frac{1}{2} \frac{GMm}{r}$	M1 A1	Allow omission of 'm' on both sides of equation (gravitational field strength = centripetal acceleration) Cancelling/rearrangement/identification of GMm/r as GPE
	b	ii	(Increase in) GPE = $(-56 - -63 \text{ MJ}) = 7 \text{ (MJ)}$ or (Increase in) KE = $0.5 \times 56 = 28 \text{ (MJ)}$ Sensible reasoning, e.g. $7+28 > 30$	M1 A1	Allow evaluation of total energy of 35 (MJ)

Question		Answer	Mark	Guidance
22	c	Level 3 (5–6 marks) Correct calculations, and advantages and limitations discussed. <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Correct calculations and an advantages discussed or Correct calculations and a limitation discussed. <i>There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Attempted calculations or a single correct calculation or incomplete explanations of advantages and/or limitations. <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i> 0 marks <i>No response or no response worthy of credit.</i>	B1 x 6	Use level of response annotations in RM Assessor Ignore general knowledge answers e.g. accidents, cost, politics Allow references to energy, energy per unit mass or potential as interchangeable Allow ecf from candidate's value for total energy per unit mass in orbit from (i.e. 35 MJ) 22bii or use of 30 (MJ) Indicative scientific points may include: Calculations • (Minimum) additional KE from aircraft=26 kJ • Additional GPE from aircraft = 100 kJ • Additional KE from equatorial launch=110 kJ • GPE calculated by mgh as an acceptable approximation • (Without taking Earth's rotation into account,) KE at equator is about 4x aircraft KE • GPE calculated from $v_g = (-)GM/r$ • Total energy = $0.5GM/r$

Question			Answer	Mark	Guidance
					Advantages • Aircraft launch provides KE and GPE • Aircraft velocity will be higher than 230 depending on where the aircraft takes off. • Less (rocket) fuel required • Aircraft launch has similar/slightly larger energy to equatorial • Equatorial launches can only happen in limited locations/aircraft launches can take place almost anywhere Limitations • Aircraft launches only suitable for small satellites. • Effects (for either) only significant for near earth orbits/low altitudes • Either launch provides very small fraction (less than 1%) of the energy required
			TOTAL	14	



23	(a)	$g = \frac{G \times 6.31 \times 10^{30}}{(1.90 \times 10^9)^2}$ $g = 117 \text{ (N kg}^{-1}\text{)}$ $2 \times \frac{0.14}{1.90} + \frac{0.42}{6.31} \quad \text{or} \quad 0.21 \quad \text{or} \quad 21\%$ (absolute uncertainty =) 25 (N kg⁻¹)	C1 C1 C1 A1	Reject 0.42/(0.14²) = 21.4 Note: final answer of $g = 117 \pm 25 \text{ (N kg}^{-1}\text{)}$ with no working scores all 4 marks. Allow correct identification of %(r) and %(m) for 1 mark max if no other marks scored. Allow alternate method using max/min values of m and r that give the correct absolute uncertainty (28)	
	(b)	(i)	The (total radiant) power (of a star) /AW	B1	
		(ii)	$(L = 4\pi r^2 \sigma T^4)$ $\text{ratio} = \sqrt{\left(\frac{6.92 \times 7500^4}{10.0 \times 4500^4}\right)}$ ratio = 2.3(1)	C1 A1	Allow 1 mark for 5.3; square root omitted Allow 1 mark for 1:2.3 or 0.43
		(iii)	$\lambda_{(\text{max})} \propto \frac{1}{T}$ Lower temperature star will have the longest wavelength, so it is Aa2	B1 B1	Allow word equation Note Must mention wavelength <u>and</u> temperature
		(iv)	From their (different) colours	B1	

		(v)	Any <u>three</u> from: • Continuous spectrum • Light / radiation / photons passes through cooler gas/star's atmosphere • Photon(s) absorbed by electron(s) • Electron(s) excited / jump / make transition to higher energy level(s) • Electron only promoted if energy of photon matches energy gap between two given levels • Photons remitted in different directions • (so) idea of contrast with non-absorbed wavelengths	B1 × 3	
		(c)	Any <u>two</u> from: • Black hole has smaller mass / radius / size • Black hole has higher density/gravitational field strength/ stronger gravitational field • black hole absorbs light / does not emit visible light • Has an escape velocity => c • No fusion in a black hole (ORA)	B1 B1	Allow black hole emits Hawking radiation
			Total	15	



17	(a)	(i)	Horizontal arrow pointing to the right.	B1	Judgement by eye
		(ii)	$2.14 \times 10^3 = \frac{2 \times \pi \times 9380 \times 10^3}{T}$ (Any subject) $T = 2.75 \times 10^4$ (s)	C1 A1	Allow 2SF answer Note: $2.75 \dots \times 10^n$ scores 1 mark.
		(iii)	$\frac{GMm}{r^2} = \frac{mv^2}{r}$ or $v^2 = \frac{GM}{r}$ $(2.14 \times 10^3)^2 = 6.67 \times 10^{-11} \times M / 9380 \times 10^3$ $M = 6.44 \times 10^{23}$ (kg)	C1 C1 A1	Allow ecf of answer for T from (a)(ii) Allow 2 SF answer Note: Use of 2.8×10^4 seconds gives 6.3×10^{23} (kg) for 3 marks. Alternative Method for C1C1 $M = 4\pi^2 R^3 / (T^2 G)$ (Databook formula re-arranged with M as subject) $M = 4\pi^2 (9380 \times 10^3)^3 / ((2.75 \times 10^4)^2 \times 6.67 \times 10^{-11})$ (i.e. M as subject) Note: In alternative method, PoT error forgetting km->m conversion gives 6.46×10^{14} (kg) for 2 marks.
	(b)	(i)	- 0.060 and 3.85 (Both to 2 sf after the decimal point)	B1	Allow - 0.06 or -0.0605 (the minus sign is required) Not: 0.06 Allow: 3.845(1) Note: Use of ln gives -0.14 and 8.854 for 0 marks.



Question		Answer	Marks	Guidance
	(ii)1	Missing data point plotted to $\pm$ half small square consistent with candidate's value. Straight best fit line drawn	B1 B1	Allow ECF from (b)(i) Allow ECF for incorrectly plotted point or data point from (i) omitted
	(ii)2	(Triangle used to determine gradient and) gradient calculation is shown to be within range -1.90 to -2.20	B1	
	(ii)3	$\lg(g) = \lg(GM) - 2\lg(r)$ or $\lg(g) = -2\lg(r) + \lg(GM)$ seen Compared with $y = mx + c$, and hence gradient = - 2	M1 A1	Allow: incorrect handling of negative g .
(c)	(i)	Any <u>two</u> from: - Direction of g for Earth and Mars are in opposite directions - For small values of r / $r <$ about $4.4 (\times 10^{10} \text{ m})$ g for Earth is greater or resultant g is towards the Earth - At r about $4.4 (\times 10^{10} \text{ m})$ the g values are the same/AW - Inverse square law for g for either planet causes curve near to either planet's surface/AW - Zero point for (resultant) g is further from the Earth (than the midpoint) since Earth has a larger mass than Mars g at Earth's surface is larger than g at surface of Mars because Earth has a larger mass than Mars	B1 $\times$ 2	Allow field / (gravitational) force for g Allow for r values larger than $4.4 (\times 10^{10} \text{ m})$ g for Mars is greater or resultant g is towards Mars



Question			Answer	Marks	Guidance
		(ii)	Any valid equation relating g_{Earth} and g_{Mars} e.g. $GM_{\text{Earth}}/r_E^2 = GM_{\text{Mars}}/r_M^2$ ratio <u>consistent</u> with values above	C1 A1	Note: the correct ratio is in the range 8.2 to 12 allowing for values of r of $4.4 \pm 0.1 (\times 10^{10} \text{ m})$ when $g = 0$
			Total	16	

